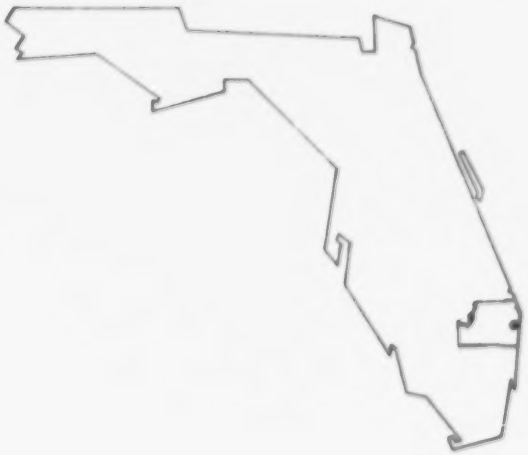
FLOOD INSURANCE STUDY

WAVE HEIGHT ANALYSIS



CITY OF DELRAY BEACH, FLORIDA
PALM BEACH COUNTY

REVISED

JANUARY 5, 1989

Federal Emergency Management Agency

COMMUNITY NUMBER - 125102

NOTICE TO
FLOOD INSURANCE STUDY USERS

Communities participating in the National Flood Insurance Program have established repositories of flood hazard data for floodplain management and flood insurance purposes. This Flood Insurance Study may not contain all data available within the repository. It is advisable to contact the community repository for any additional data.

This publication incorporates revisions to the original Flood Insurance Study. These revisions are presented in Section 7.0.

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1.0 INTRODUCTION

1.1 Background and Purpose

The Federal Emergency Management Agency recently adopted recommendations by the National Academy of Sciences to include prediction of wave heights in Flood Insurance Studies for coastal communities subject to storm surge flooding, and to report the estimated wave crest elevations as the base flood elevations on Flood Insurance Rate Maps (FIRMs).

Previously, FIRMs were produced showing only the stillwater storm-surge elevations due to the lack of a suitable and generally applicable methodology for estimating the wave crest elevations associated with storm surges. These stillwater elevations were subsequently stipulated in community flood plain management ordinances as the minimum elevation of the first floor of new construction. Communities and individuals had to consider the additional hazards of velocity waters and wave action on an ad hoc basis. Because there has been a pronounced tendency for buildings to be constructed only to meet minimum standards, without consideration of the additional hazard due to wave height, increasing numbers of people could unknowingly be accepting a high degree of flood-related personal and property risk in coastal areas subject to wave action. Therefore, the Federal Emergency Management Agency has pursued the development of a suitable methodology for estimating the wave crest elevations associated with storm surges. The recent development of such a methodology by the National Academy of Sciences (Reference 1) has led to the adoption of wave crest elevations for use as the base flood elevations in coastal communities.

Since 1871, 12 hurricanes have passed through Palm Beach County. Among the more severe were the storms of September 1928, September 1947, October 1947, and August-September 1964. The hurricane of September 1928 is considered one of the most violent ever to strike Florida. The center of the storm smashed into the West Palm Beach area with winds in excess of 100 miles per hour. Nearly 95 percent of the commercial and residential property in the West Palm Beach area was damaged. High tides ranged from 8 feet in Lake Worth to 10 feet at Palm Beach. Severe wave action was responsible for the washout of several bridges crossing Lake Worth. The hurricane of October 1947 climaxed an extremely wet rainy season in which precipitation in the county ranged from 70 to 85 inches.

The City of Delray Beach, Florida, is located on the open coast and is subject to flooding from tidal surges associated with hurricanes. The purpose of this study is to revise the FIRM for Delray Beach to include the effects of wave action associated with flooding from the Atlantic Ocean at the open coast and the Intracoastal Waterway.

2.0 INVESTIGATIONS

2.1 Previous Studies

Stillwater elevations for hurricane surges with 10-, 50-, 100-, and 500-year return periods were determined by Tetra Tech, Inc. for all areas of Palm Beach County and its incorporated communities inundated by tidal flooding. The 100-year stillwater elevations were used as base flood elevations for the FIRM that has been prepared for Delray Beach (Reference 2).

These elevations were determined by the joint probability method (Reference 3). The storm populations were described by probability distributions of five parameters which influence surge heights. These parameters were central pressure depression (which measures the intensity of the storm), radius to maximum winds, forward speed of the storm, shoreline crossing point, and crossing angle. These characteristics were described statistically, based on an analysis of observed storms in the vicinity of Palm Beach County. Primary sources of data for the parameters were the National Weather Service (Reference 4); Cry (Reference 5); Ho, Schwerdt, and Goodyear (Reference 6); and, the National Hurricane Research Project (Reference 7).

A numerical hydrodynamic model of the region was used to simulate the coastal surge generated by any chosen storm (that is, any combination of the five storm parameters defined previously). By performing such simulations for a large number of storms each of known total probability, the frequency distribution of surge height can be established as a function of coastal location. These distributions incorporate the large scale surge behavior, but do not include an analysis of the added effects associated with much finer scale wave phenomena, such as wave height, setup, or runup. The astronomical tide for the region was statistically combined with the computed storm tide to yield recurrence intervals of total water level.

The stillwater elevations developed for the previous FIRM were used as starting water-surface elevations for the wave height analysis presented herein.

This report is authoritative for purposes of the National Flood Insurance Program. Data presented herein supersedes all previous flood elevation determinations.

2.2 Data Collection and Review

All available source data applicable for the wave height analysis were collected and reviewed. Because wave height calculations are based on such parameters as the size and density of vegetation, natural barriers (such as sand dunes), buildings, and other manmade structures, it was necessary to obtain detailed information on the physical and cultural features of the study area.

Officials of the City of Delray Beach and Palm Beach County were contacted for maps and other possible data sources to be used in the analysis. In addition the Florida Department of Transportation; the Florida Department of Natural Resources, Bureau of Beaches and Shores; the U.S. Army Corps of Engineers, Jacksonville District; the National Ocean Survey; the U.S. Fish and Wildlife Service; the South Florida Water Management District; A.V. Strock and Associates; and Abrams Aerial Survey were contacted and all applicable data sources were obtained.

The principal source materials used for the wave height analysis are described below.

a. Topographic data (ground elevations, seawall elevations, and locations of physical features) were determined using U.S. Geological Survey topographic maps at a scale of 1:24,000, with a contour interval of 5 feet (Reference 8); National Ocean Survey storm evacuation maps at a scale of 1:32,500, with a contour interval of 5 feet (Reference 9); and beach profiles of the immediate Atlantic coast area obtained from the Florida Department of Natural Resources (Reference 10).

b. Stereoscopic aerial photography at a scale of 1:12,000 and National Wetlands Inventory Maps at a scale of 1:24,000 were used to determine vegetation and building parameters and to supplement the topographic maps for locations of physical features (References 11 and 12).

2.3 Wave Height Analysis

The methodology for analyzing the effects of wave heights associated with coastal storm surge flooding is described in the National Academy of Sciences report (Reference 1). This method is based on the following major concepts. First, depth-limited waves in shallow water reach a maximum breaking height that is equal to 0.78 times the stillwater depth. The wave crest is 70 percent of the total wave height above the stillwater level. The second major concept is that wave height may be diminished by dissipation of energy due to the presence of obstructions, such as sand dunes, dikes and seawalls, buildings, and vegetation. The amount of energy dissipation is a function of the physical characteristics of the obstruction and is determined by procedures prescribed in Reference 1. The third major concept is that wave height can be regenerated in open fetch areas due to the transfer of wind energy to the water. This added energy is related to fetch length and depth.

Wave heights were computed along transects (cross section lines) in accordance with the Users Manual for Wave Height Analysis (Reference 13). The transects were located along the coastline as shown in Figure 1. They were located with consideration given to the physical and cultural characteristics of the land so that they would closely represent conditions in their locality. Transects were spaced close together in areas of complex topography and dense development. In areas having more uniform characteristics, they were spaced at larger intervals. It was also necessary to locate transects in areas where unique flooding existed and in areas where computed wave heights varied significantly between adjacent transects.

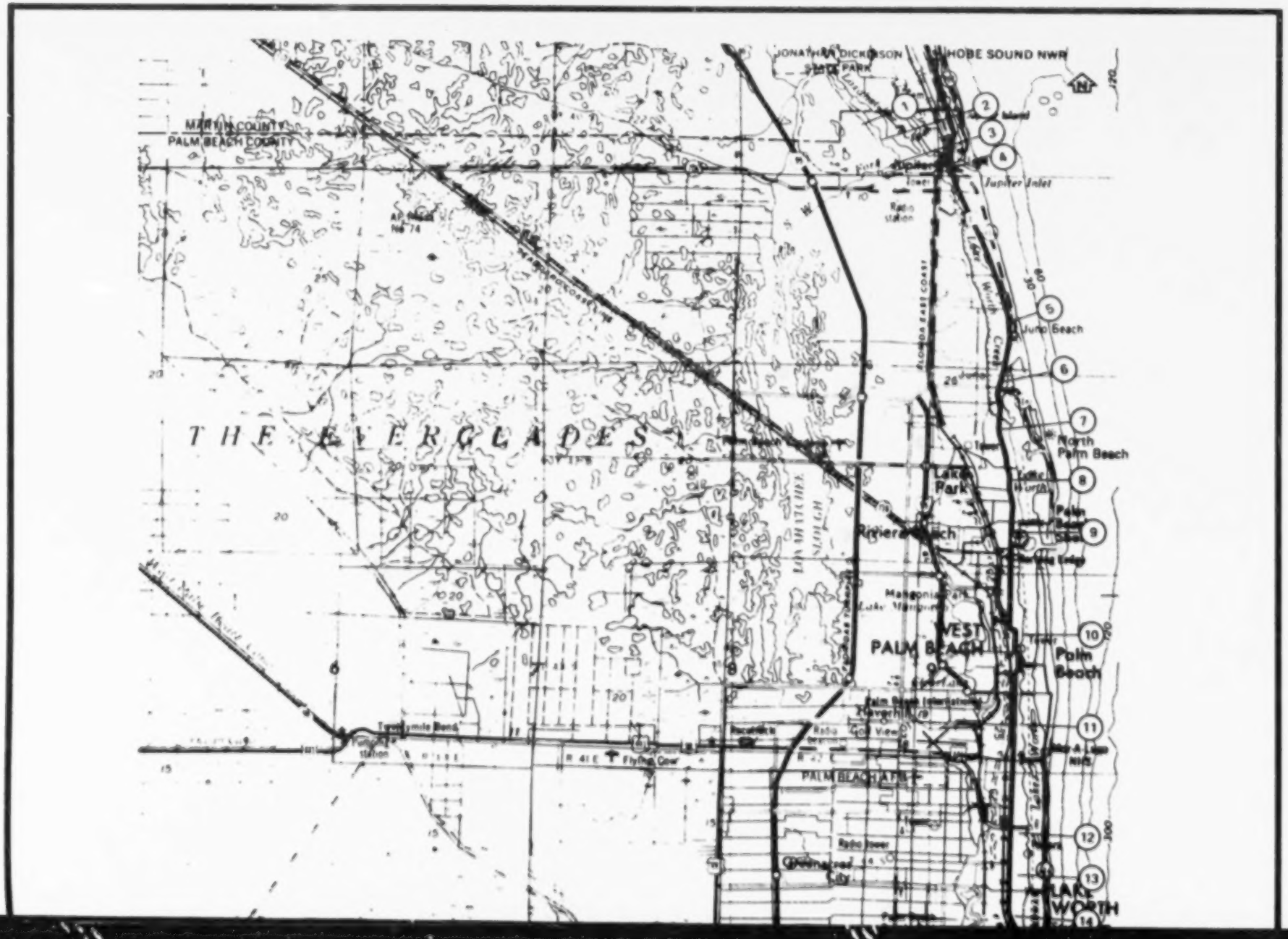

JONATHAN DICKINSON STATE PARK
HOBE SOUND NWR
MARTIN COUNTY
PALM BEACH COUNTY
Jupiter Inlet
Juno Beach
THE EVERGLADES
North Palm Beach
Lake Park
Riviera Beach
WEST PALM BEACH
Palm Beach
PALM BEACH INTL
LAKE WORTH

FIGURE 1A

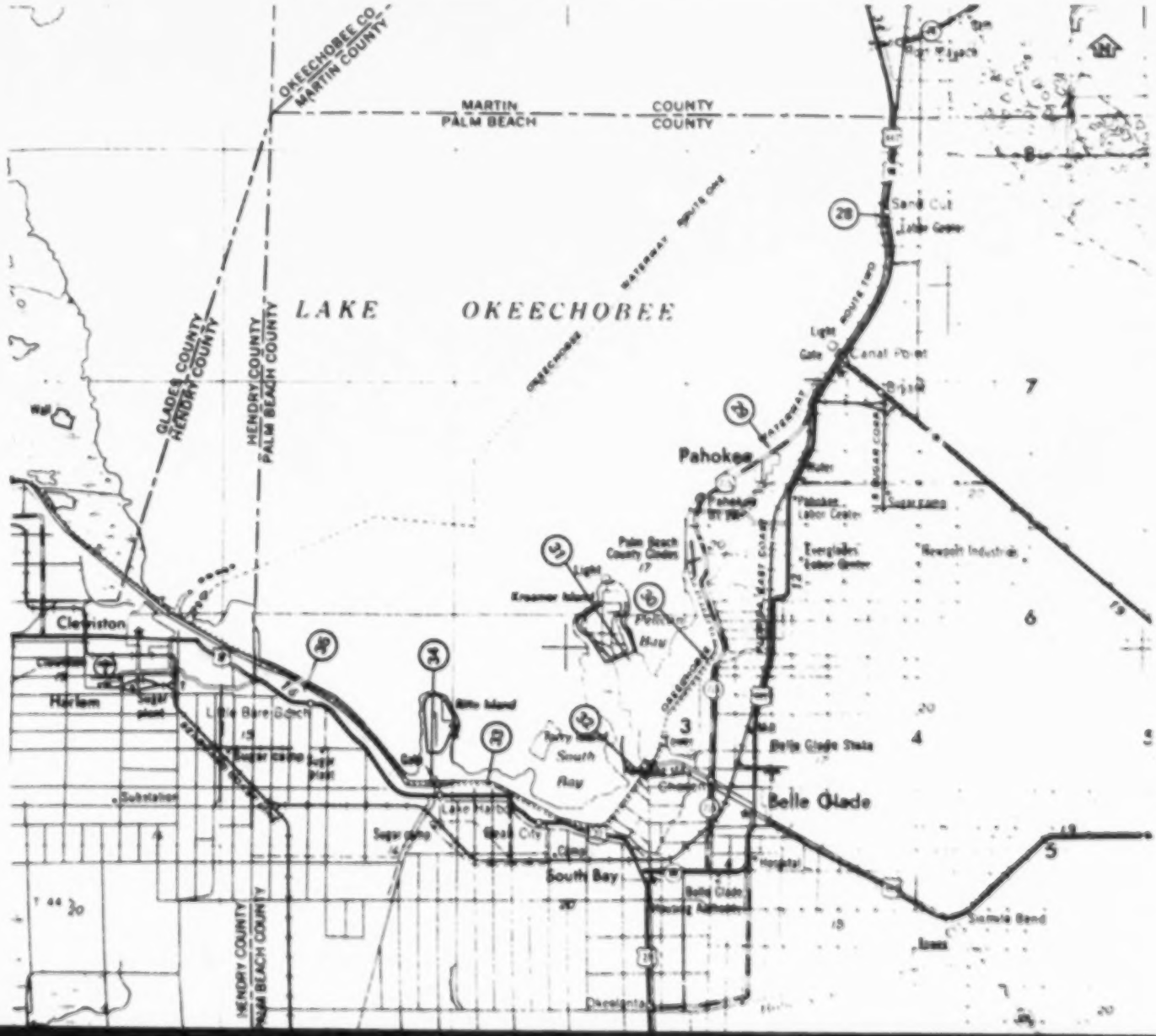
FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY OF DELRAY BEACH, FL
(PALM BEACH CO.)

APPROXIMATE SCALE

4 0 4 8 12 MILES

TRANSECT LOCATION MAP


OKEECHOBEE CO.
MARTIN COUNTY
MARTIN COUNTY
PALM BEACH COUNTY
GLADES COUNTY
HENDRY COUNTY
HENDRY COUNTY
PALM BEACH COUNTY
LAKE OKEECHOBEE
Pahokee
Clewiston
Harlem
Belle Glade
South Bay
Belle Glade State
Lake Harbor
Sand Cut
Canal Point
Everglades
Torry Island
South Bay
Pahokee
Clewiston
Belle Glade
Harlem
Lake Harbor
South Bay
Belle Glade State
Canal Point
Everglades
Sand Cut
Torry Island
Pahokee
Clewiston
Belle Glade
Harlem
Lake Harbor
South Bay
Belle Glade State
Canal Point
Everglades
Sand Cut
Torry Island

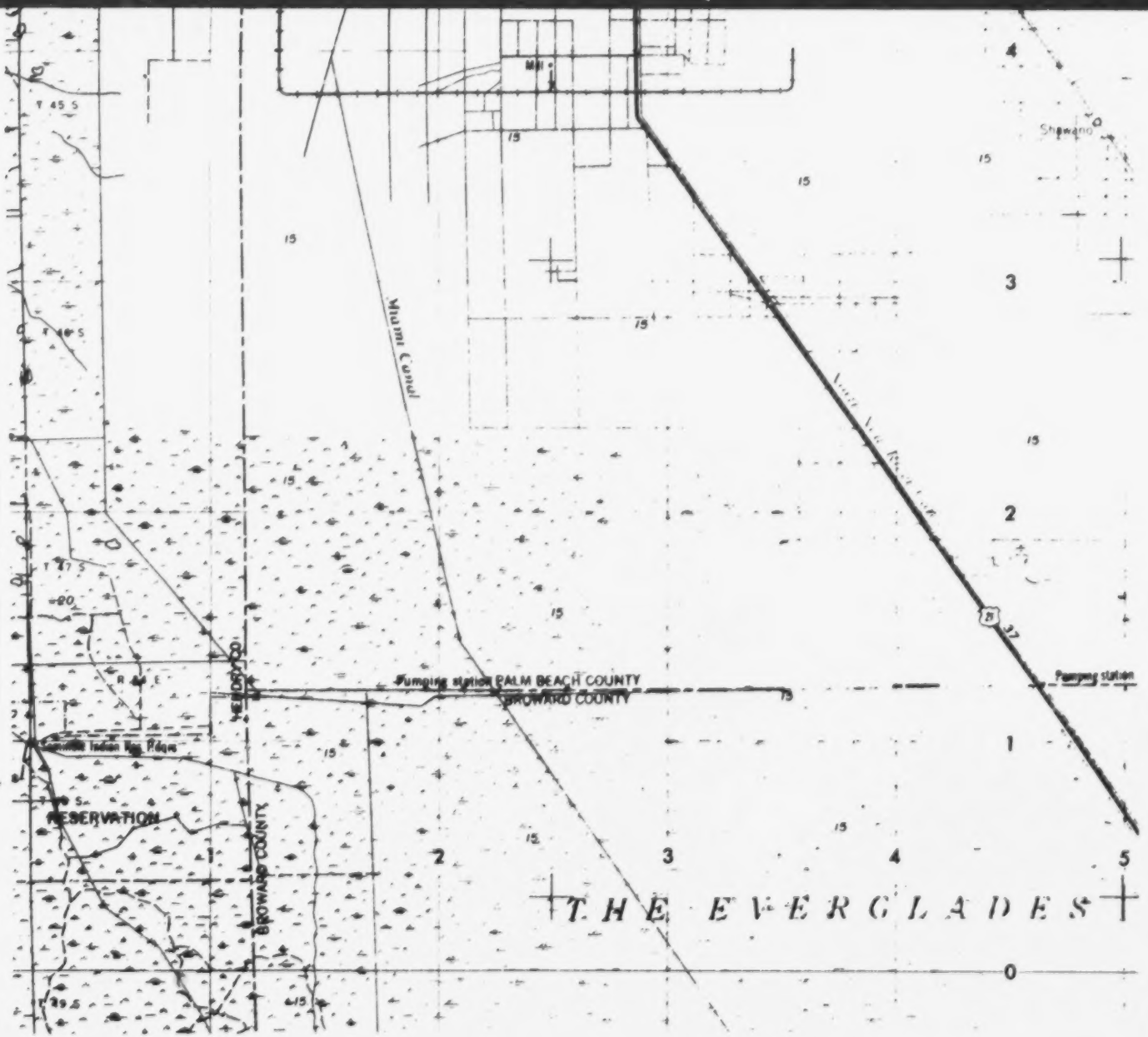


FIGURE 1B

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY OF DELRAY BEACH, FL
(PALM BEACH CO.)

TRANSECT LOCATION MAP

Each transect was taken perpendicular to the shoreline and extended to the inland limit of tidal flooding. Along each transect, wave heights and elevations were computed considering the combined effects of changes in ground elevation, vegetation, and physical features. The stillwater elevations for the 100-year flood were used as the starting elevations for these computations. Wave heights were calculated to the nearest 0.1 foot, and wave elevations were determined at whole-foot increments along the transects. The location of the 3-foot breaking wave for determining the terminus of the V Zone (area with velocity wave action) was also computed at each transect. Table 1 provides a listing of the transect locations and stillwater elevations, as well as maximum wave crest elevations in the vicinity of Delray Beach.

Figure 2 is a profile for a typical transect illustrating the effects of energy dissipation and regeneration on a wave as it moves inland. This figure shows the wave elevations being decreased by obstructions, such as buildings, vegetation, and rising ground elevations, and being increased by open, unobstructed wind fetches. Actual wave conditions in Delray Beach may not necessarily include all the situations illustrated in Figure 2.

After analyzing wave heights along each transect, wave elevations were interpolated between transects. Various source data were used in the interpolation, including topographic maps (References 8 and 9), beach profiles (Reference 10), and aerial photographs (Reference 11), along with engineering judgment. Controlling features affecting the elevations were identified and considered in relation to their positions at a particular transect and their variation between transects.

2.4 Results

Rapidly rising sand dunes and seawalls provide considerable protection along the open coast of Palm Beach County. These dunes and seawalls are expected to remain intact during the 100-year storm surge and are considered effective wave energy dissipators. Much of the shoreline along the Intracoastal Waterway is protected by bulkheads. These bulkheads are capable of dissipating wave energy.

Only a small portion of Delray Beach is effected by wave action. Wave heights greater than 3 feet associated with the 100-year storm surge on the Atlantic coast are diminished near the open coast by ascending ground slope and seawalls. The maximum wave crest elevation at the Atlantic Ocean shoreline is 11 feet.

Much of the Intracoastal Waterway is not wide enough to allow measurable wave generation except in local areas, such as Tropic Isle Harbor, where wave crest elevations reach 8 feet.

3.0 FLOOD PLAIN MANAGEMENT APPLICATIONS

A prime purpose of the National Flood Insurance Program is to encourage local governments to adopt sound flood plain management programs designed to reduce future flood losses. The FIRM for Delray Beach has been revised to incor-

Table 1.
Transect Locations, Stillwater Elevations, and Maximum Wave Crest Elevations

Transect	Location	Elevation (Feet NGVD) Stillwater	Wave Crest
20	Delray Beach - From the Atlantic coastline westward across the Intracoastal Waterway to the limit of inundation by the 100-year storm surge; crosses Venetian Drive between Shulson Street and Langer Way	7.0[1]	11[1]
21	Highland Beach/Delray Beach - From the east side of the Intracoastal Waterway westward across the Intracoastal Waterway and Tropic Isle Harbor to the limit of inundation by the 100-year storm surge in Delray Beach	7.3[2]	8[2]

[1]Atlantic Ocean
[2]Intracoastal Waterway

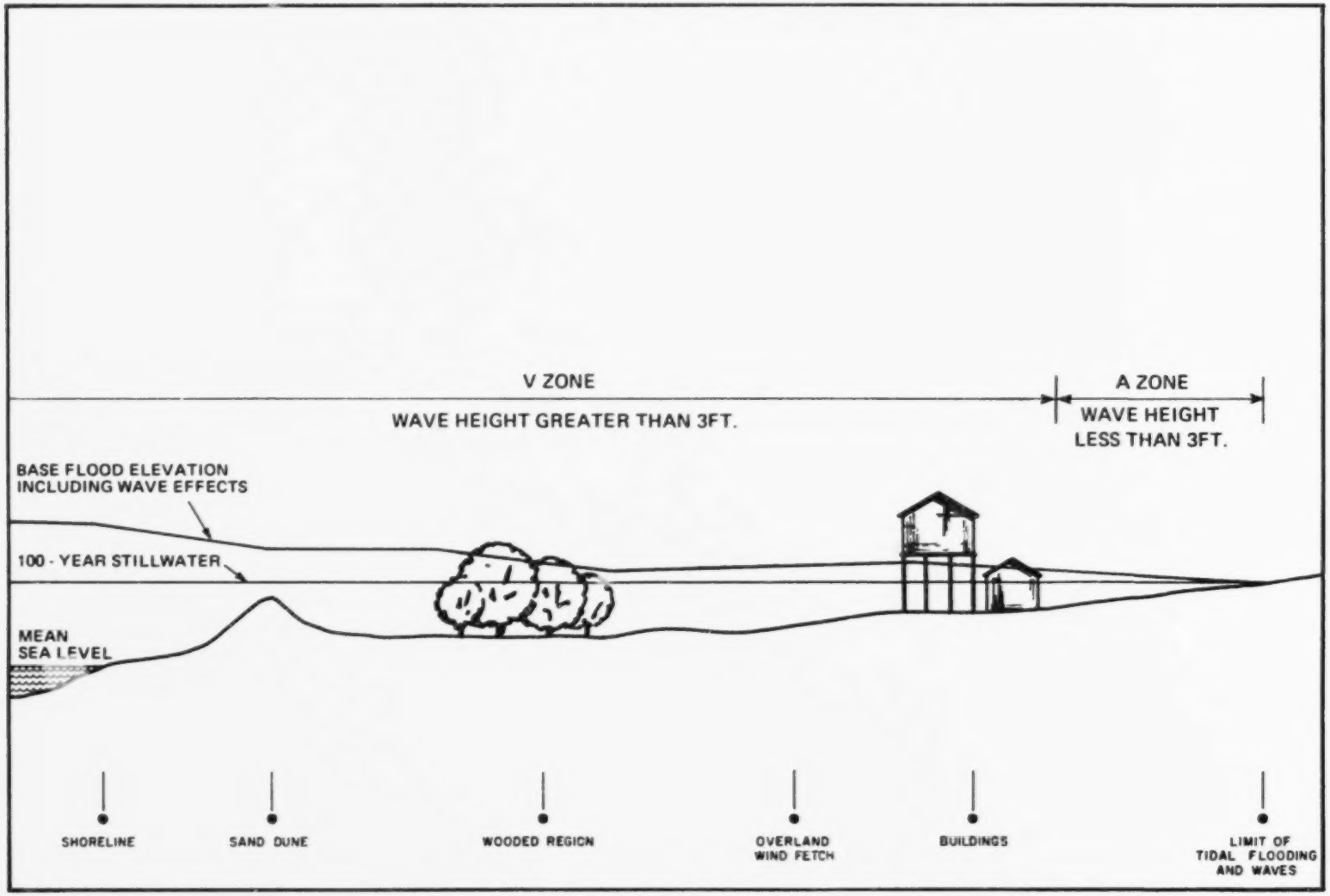


FIGURE 2
TYPICAL TRANSECT SCHEMATIC

porate the latest available information, including wave height data, to assist this community in developing the most appropriate and effective flood plain management measures.

3.1 Flood Boundaries

In order to provide a national standard without regional discrimination, the 100-year flood has been adopted by the Federal Emergency Management Agency as the base flood for purposes of flood plain management. This flood has a 1 percent chance of being equalled or exceeded each year and is expected to be exceeded once on the average during any 100-year period. The risk of having a flood of this magnitude or greater increases when periods longer than 1 year are considered. For example, over a 30-year period, there is a 26 percent chance of experiencing a flood equal to or greater than the 100-year flood. The 500-year flood plain is also shown on the FIRM to indicate areas of moderate flood hazards.

Areas inundated by the 100-year flood are shown as A and V Zones on the community's FIRM. It is in these areas that the Federal Emergency Management Agency requires local communities to exercise flood plain management measures as a condition for participation in the National Flood Insurance Program.

3.2 Base Flood Elevations

Areas within the communities studied by detailed engineering methods have base flood elevations established in A and V Zones. These are the elevations of the base (100-year) flood relative to the National Geodetic Vertical Datum of 1929. In coastal areas affected by wave action, base flood elevations are generally maximum at the open coast shoreline. These elevations generally decrease in a landward direction at a rate dependent on the presence of obstructions capable of dissipating the wave energy. Where possible, changes in base flood elevations have been shown in 1-foot increments on the FIRMs. However, where the scale did not permit, 2- or 3-foot increments were sometimes used. Base flood elevations shown in the wave action areas represent the average elevation within the zone. Current program regulations generally require that all new construction be elevated such that the first floor, including basement, is above the base flood elevation in A and V Zones.

3.3 Velocity Zones

The U.S. Army Corps of Engineers (Reference 14) has established the 3-foot breaking wave as the criterion for identifying coastal high hazard zones. This was based on a study of wave action effects on structures. This criterion has been adopted by the Federal Emergency Management Agency for the determination of V Zones. Because of the additional hazards associated with high-energy waves, the National Flood Insurance Program regulations require much more stringent flood plain management measures in these areas, such as elevating structures on piles or piers. In addition, insurance rates in V Zones are higher than those in A Zones with similar numerical designations.

The location of the V Zone is determined by the 3-foot breaking wave as discussed previously. The detailed analysis of wave heights performed in this study

allowed a much more accurate location of the V Zone to be established. The V Zone generally extends inland to the point where the 100-year flood depth is insufficient to support a 3-foot breaking wave.

4.0 INSURANCE APPLICATION

The assignment of proper actuarial insurance rates requires that frequency and depth of flooding be estimated as accurately as possible. Because waves can add considerably to expected flood depths, it is important that insurance rates consider this additional hazard. The Federal Emergency Management Agency has developed a process to transform the data from this study into flood insurance criteria. This process includes the determination of Flood Hazard Factors and the designation of flood insurance zones.

4.1 Flood Hazard Factors

The Flood Hazard Factor (FHF) is the device used to correlate flood information with insurance rate tables. Correlations between property damage from floods and their FHF are used to set actuarial insurance premium rate tables.

The FHF is shown as a three-digit code that expresses the difference between the 10- and 100-year flood elevations to the nearest 0.5 foot. For example, if the difference between water-surface elevations of the 10- and 100-year floods is 0.7 foot, the FHF is 005; if the difference is 1.4 feet, the FHF is 015; if the difference is 5.0 feet, the FHF is 050. When the difference between the 10- and 100-year water-surface elevations is greater than 10.0 feet, the FHF is computed to the nearest foot.

4.2 Flood Insurance Zones

After wave elevations for the 100-year storm surge were determined and mapped, the study areas were divided into zones, each having a specific flood potential and FHF. Each zone was assigned one of the following flood insurance zone designations:

Zone V8:	Special Flood Hazard Areas inundated by the 100-year flood, and that have additional hazards due to velocity (wave action); base flood elevations shown, and zones subdivided according to FHFs.
Zones A5, A6, and A7:	Special Flood Hazard Areas inundated by the 100-year flood, with base flood elevations determined and zone designations assigned according to the FHFs.
Zone B:	Areas between the Special Flood Hazard Areas and the limits of the 500-year

	flood plain, including areas that are protected from the 100- and 500-year floods by dike, levee, or other water control structure; and areas subject to certain types of 100-year shallow flooding where depths are less than 1.0 foot, or where the contributing drainage area is less than 1 square mile. Zone B is not subdivided.
Zone C:	Areas not subject to flooding by the 500-year flood. Zone C is not subdivided.
Zone D:	Areas of undetermined, but possible flood hazard.

Table 2, "Flood Insurance Zone Data," summarizes the FHFs, flood insurance zones, and base flood elevations for each flooding source in the study area.

4.3 Flood Insurance Rate Map

After flood insurance zones were established for the study area, the FIRM for Delray Beach was revised to incorporate the new zone information. This map (Exhibit 1) contains the official delineation of flood insurance zones and base flood elevations.

5.0 OTHER STUDIES

FIRMS for the incorporated communities of Boca Raton, Boynton Beach, Briny Breezes, Gulf Stream, and Highland Beach, and Palm Beach County are being revised concurrently with Delray Beach to include wave height analysis. The revised studies for these communities will be in agreement with this study.

6.0 REFERENCES

1. National Academy of Sciences, Methodology for Calculating Wave Action Effects Associated With Storm Surges, 1977

2. U.S. Department of Housing and Urban Development, Federal Insurance Administration, Flood Insurance Rate Map, City of Delray Beach, Florida, Scale 1:12,000, 1979

3. U.S. Department of Commerce, Environmental Science Services Administration, Technical Memorandum WBTM Hydro 11, Joint Probability Method of Tide Frequency Analysis, V.A. Myers, April 1970

4. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Tropical Cyclone Deck 993, 1975

Table 2. Flood Insurance Zone Data

Flooding Source	Stillwater Elevation 10-Year	50-Year	100-Year	500-Year	FHF	Zone	Base Flood Elevation (Feet NGVD)*
Atlantic Ocean Open Coast	4.5	6.3	7.0	8.5	040	V8	7 to 11
Intracoastal Waterway	4.7	6.6	7.3	9.0	030	A6	8
					025	A5	7

*Due to map scale limitations, base flood elevations shown on the FIRM may represent average elevations for the zones depicted.

5. U.S. Department of Commerce, Weather Bureau, Technical Paper No. 55, Tropical Cyclones of the North Atlantic Ocean 1871 - 1963, G.W. Cry, 1965

6. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Technical Report NWS-15, Climatological Characteristics of Hurricanes, F.P. Ho, R.W. Schwerdt, and H.V. Goodyear, July 1975

7. U.S. Department of Commerce, National Hurricane Research Project, Report No. 5, Survey of Meteorological Factors, March 1957

8. U.S. Department of the Interior, Geological Survey, 7.5-Minute Series Topographic Maps, Scale 1:24,000, Contour Interval 5 feet: Delray Beach, Florida (1962), Photorevised (1973)

9. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, Storm Evacuation Maps T-15057 and T-15056, Scale 1:62,500, Contour Interval 5 feet: Fort Lauderdale, Florida (1976); West Palm Beach, Florida (1976)

10. Florida Department of Natural Resources, Bureau of Beaches and Shores, Palm Beach County, Florida, Beach Profiles, Scale 1:600, 1974

11. Federal Emergency Management Agency, Aerial Photography of Palm Beach County, Florida, Scale 1:12,000, March 1981

12. U.S. Department of the Interior, Fish and Wildlife Service, National Wetlands Inventory Maps, Scale 1:24,000: Delray Beach, Florida

13. Federal Emergency Management Agency, Users Manual for Wave Height Analysis, Revised February 1981

14. U.S. Army Corps of Engineers, Galveston District, Guidelines for Identifying Coastal High Hazard Zones, June 1975

U.S. Department of Housing and Urban Development, Federal Insurance Administration, Coastal Flooding Handbook, Parts I and II, Tetra Tech, Inc., May 1977

7.0 REVISIONS DESCRIPTION

This section has been added to provide information regarding significant revisions made since the original Flood Insurance Study was printed. Future revisions may be made that do not result in the republishing of the Flood Insurance Study report. To assure that any user is aware of all revisions, it is advisable to contact the community repository of flood hazard data located at the Public Works Complex, 434 South Swinton Avenue, Delray Beach, Florida.

7.1 First Revision (Revised January 5, 1989)

a. Acknowledgments

The information for this Revisions Description was obtained from the Flood Insurance Studies for the contiguous communities of the City of Boca Raton, Florida, the City of Boynton Beach, Florida, and Palm Beach County, Florida (References 15-17). The Federal Emergency Management Agency reviewed and accepted these data for purposes of this revision.

b. Scope

Based on the studies for the contiguous communities, this revision incorporated flooding information for areas throughout Delray Beach, primarily west of Interstate 95, for which Special Flood Hazard Areas were previously undetermined. The detailed flooding information in this revision changes the areas that were originally designated as Zone D. The revised floodplain boundaries were determined using U.S. Geological Survey flood-prone maps (Reference 18) and engineering judgment.

c. Insurance Application

For flood insurance rating purposes, flood insurance zone designations are assigned to a community based on the results of the engineering analyses. These zones are as follows:

Zone A

Zone A is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the Flood Insurance Study by approximate methods. Because detailed hydraulic analyses are not performed for such areas, no base flood elevations or depths are shown within this zone.

Zone AE

Zone AE is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the Flood Insurance Study by detailed methods. Whole-foot base flood elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone.

Zone V

Zone V is the flood insurance rate zone that corresponds to the 100-year coastal floodplains that have additional hazards associated with storm waves. Because approximate hydraulic analyses are performed for such areas, no base flood elevations are shown within this zone.

Zone VE

Zone VE is the flood insurance rate zone that corresponds to the 100-year coastal floodplains that have additional hazards associated with storm waves. Whole-foot base flood elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone.

Zone X

Zone X is the flood insurance rate zone that corresponds to areas outside the 100-year floodplain, areas of 100-year flooding where average depths are less than 1 foot, areas of 100-year flooding where the contributing drainage area is less than 1 square mile, and areas protected from the 100-year flood by levees. No base flood elevations or depths are shown within this zone.

The reach determinations, Flood Hazard Factors, and flood insurance zones presented in Sections 5.1, 5.2, and 5.3 of this report and Table 2, Flood Insurance Zone Data, are no longer applicable.

d. Flood Insurance Rate Map

The Flood Insurance Rate Map is designed for flood insurance and floodplain management applications.

For flood insurance applications, the map designates flood insurance rate zones as described in Section 7.1.c and, in the 100-year floodplains that were studied by detailed methods, shows selected whole-foot base flood elevations or average depths. Insurance agents use the zones and base flood elevations in conjunction with information on structures and their contents to assign premium rates for flood insurance policies.

For floodplain management applications, the map shows by tints, screens, and symbols the 100- and 500-year floodplains, the floodways, and the locations of selected cross sections used in the hydraulic analyses and floodway computations.

e. Other Studies

Flood Insurance Studies published for the Cities of Boca Raton and Boynton Beach, Florida, and Palm Beach County, Florida (References 15-17) are in agreement with this revised study.

f. References and Bibliography

15. Federal Emergency Management Agency, Flood Insurance Study, City of Boca Raton, Palm Beach County, Florida, September 1984.

16. ————, Flood Insurance Study, City of Boynton Beach, Palm Beach County, Florida, September 1982.

17. ----------, Flood Insurance Study, Palm Beach County, Unincorporated Areas, Florida, October 1982.

18. U.S. Geological Survey, 7.5. Minute Series Maps of Flood-Prone Areas, Scale 1:24000, Contour Interval 5 Feet: University Park, Florida, 1974; Delray Beach, Florida, 1974.